Lecture Module - Strain Gauges

ME3023 - Measurements in Mechanical Systems

Mechanical Engineering

Tennessee Technological University

Module 9 - Strain Gauges

Module 9 - Strain Gauges

- Topic 1 - Measuring Strain
- Topic 2 - The Wheatstone Bridge
- Topic 3 - P3 Strain Indicator

Topic 1 - Measuring Strain

- Motivation in Design
- Stress and Strain
- The Strain Gauge
- Engineering Applications

Motivation in Design

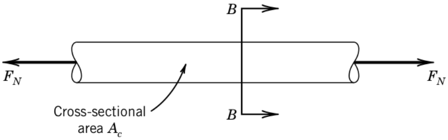
The design of load-carrying components for machines and structures requires information concerning the distribution of forces within the particular component. Proper design of devices such as shafts, pressure vessels, and support structures must consider load-carrying capacity and allowable deflections. Mechanics of materials provides a basis for predicting these essential characteristics of a mechanical design, and provides the fundamental understanding of the behavior of load-carrying parts. However, theoretical analysis is often not sufficient, and experimental measurements are required to achieve a final design.

Text: Theory and Design of Mechanical Measurements

Motivation in Design

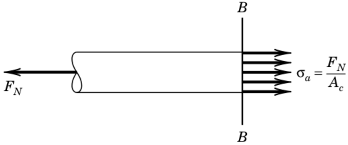
Stress and Strain

Consider a member under uni-axial loading. The strain is defined as the ratio of the change in length to the original length of the component.



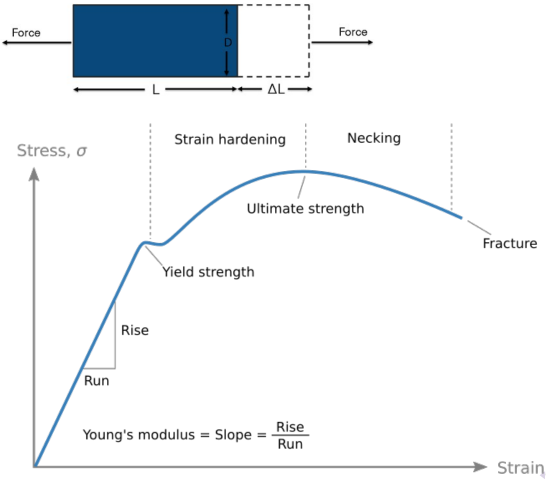
$$\sigma_a = \frac{F_N}{A_c}$$

$$\epsilon_a = \frac{\delta_L}{L}$$



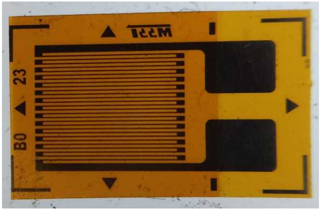
$$\sigma_a = E_m \epsilon_a$$

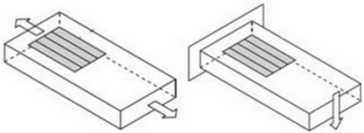
Stress and Strain



The Strain Gauge

... the ideal sensor for the measurement of strain would (1) have good spatial resolution, implying that the sensor would measure strain at a point; (2) be unaffected by changes in ambient conditions; and (3) have a high-frequency response for dynamic (time-resolved) strain measurements. A sensor that closely meets these characteristics is the bonded resistance strain gauge.





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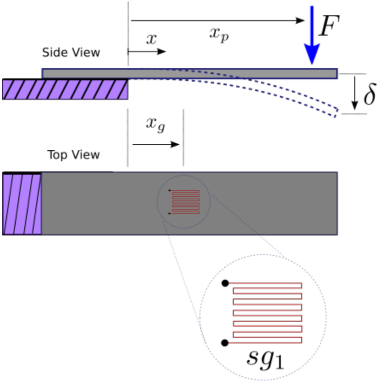
The Strain Gauge

Strain gauges can be mounted in different ways for different purposes. We will begin with a single gauge mounted in the axial direction.



Engineering Applications

- Segway back to *Motivation in Design* (Slide 1) ...
- Aerospace
- Infrastructure
- Short article on applications here.

some reference

Engineering Applications

Engineering Applications

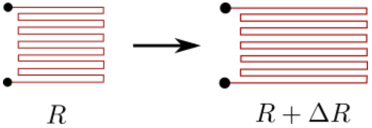
Topic 2 - The Wheatstone Bridge

- Resistive Gauges
- The Bridge Circuit
- Balancing the Bridge
- Gauge Sensitivity

Resistive Gauges

The resistive strain gauge, aka *metallic gauge*, is bonded to the surface so that is deforms with the specimen. The change in length of the bonded gauge causes a change in resistance which is used as a measure of strain.

$R = \rho_e L/A_c = fn(L, ...)$



This is an exaggerated picture so the change is very small...

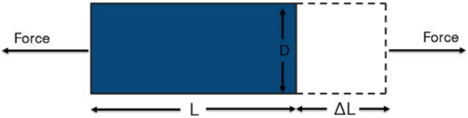
Images: T.Hill

Resistive Gauges

The Gauge Factor is typically used instead of the physical parameters.

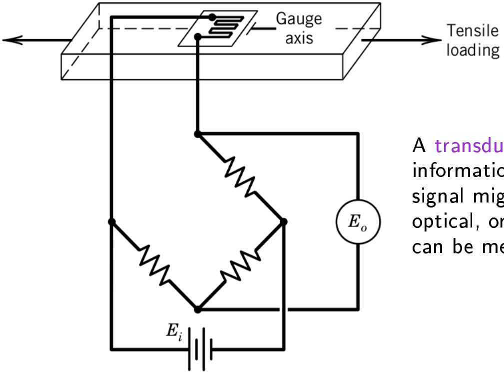
$$GF \equiv \frac{\delta R/R}{\delta L/L} = \frac{\delta R/R}{\epsilon_a}$$

This number relates the relative change in resistance to the measured strain.



Images: NI

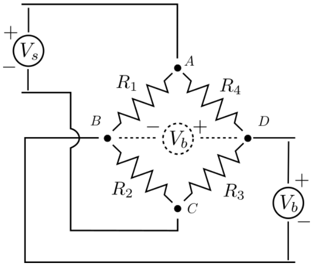
The Bridge Circuit



A transducer converts the sensed information into a detectable signal. The signal might be mechanical, electrical, optical, or may take any other form that can be meaningfully recorded.

Text. Images: Theory and Design for Mechanical Measurements

The Bridge Circuit



How does the bridge circuit work as a transducer?

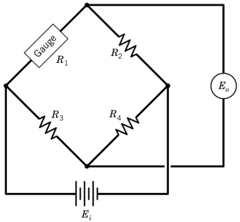
Use KVL and the voltage divider rule find the relationship between the two voltages.

$$V_b = \left(\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2} \right) \times V_s$$

Images: T.Hill

Balancing the Bridge

If all four resistors are equal the bridge voltage will equal zero and the bridge is said it be balanced. One or more resistors in the circuit is replaced by a strain gauge and bridge voltage is used as a measure of change in resistance and therefore strain.



This gives a linear calibration curve with a convenient zero offset.

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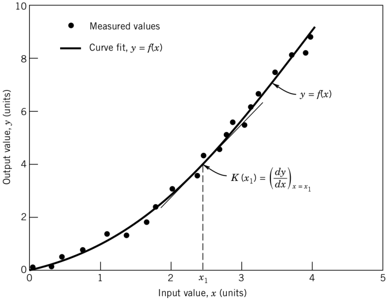
Balancing the Bridge

Balancing the Bridge

Gauge Sensitivity



Assume $R = 120\Omega$ for all resistors and the bridge is balanced in a condition of zero strain. What is the static sensitivity of the gauge and bridge circuit described?

K=

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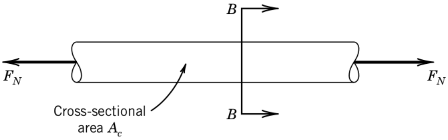
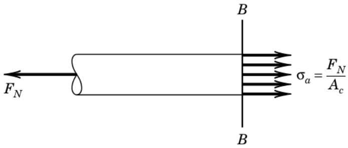
Gauge Sensitivity

Topic 3 - P3 Strain Indicator

- Units of Microstrain
- Quarter, Half, and Full Configuration
- Operating the P3
- Alternative Solutions

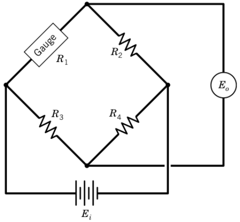
Units of Microstrain

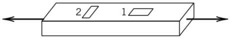


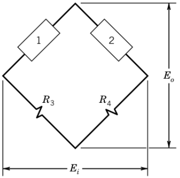


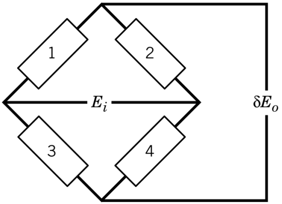
Units of Microstrain

Quarter, Half, and Full Configuration

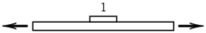
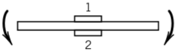
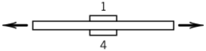
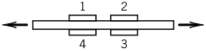
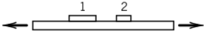
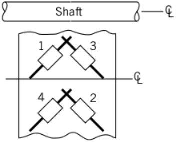




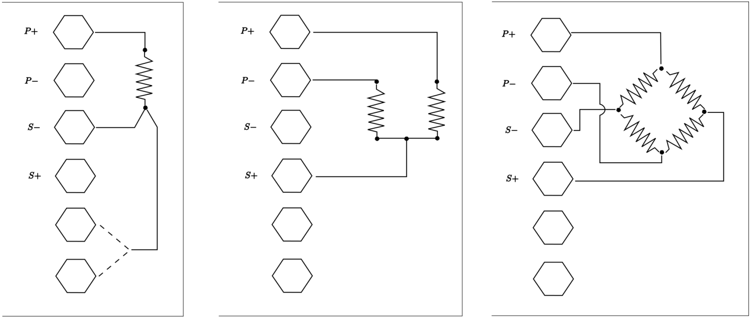




Quarter, Half, and Full Configuration

	Arrangement	Compensation Provided	Bridge Constant κ
	Single gauge in uniaxial stress	None	$\kappa = 1$
	Two gauges sensing equal and opposite strain—typical bending arrangement	Temperature	$\kappa = 2$
	Two gauges in uniaxial stress	Bending only	$\kappa = 2$
	Four gauges with pairs sensing equal and opposite strains	Temperature and bending	$\kappa=4$
	One axial gauge and one Poisson gauge		$\kappa= 1 +\nu$
	Four gauges with pairs sensing equal and opposite strains—sensitive to torsion only; typical shaft arrangement.	Temperature and axial	$\kappa = 4$

Operating the P3



Operating the P3

Operating the P3

- The instructions are on the unit.
- The balancing process is completed after changing any wiring.

Operating the P3

Alternative Solutions

- The P3500/P3 is expensive, but it is a reliable instument. The ME department has used them for years with success.
- The manufacturer *Vishay Group* has a *more* modern solution with DAQ and multiple channels.
- There are a variety of low cost alternative options available.
  - Sparkfun - strain gauge basics
  - Robot Shop
  - elecrow